EUROPEAN CENTRAL BANK

EUROSYSTEM

Bridging innovation and stability: the Eurosystem's exploratory work on new technologies for wholesale central bank money settlement

June 2025

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Recent developments in distributed ledger technology (DLT) and tokenisation have sparked growing interest across the financial sector. While their full implications remain to be seen, these technologies are likely to offer new ways of improving the settlement of financial transactions. They could also help address the shortcomings in today's capital and payment markets ecosystem – namely fragmentation, complexity and technological inefficiencies – that are impeding progress towards a sustainable digital savings and investments union in Europe.

It was against this background that the Eurosystem launched an exploratory initiative to understand more clearly how DLT could be used for settling wholesale transactions in central bank money. Between May and November 2024 the Eurosystem engaged with 64 market participants across different sectors and countries. Together, we explored a range of use cases by conducting trials involving real transactions as well as experiments using mock scenarios. Nearly €1.6 billion in central bank money was settled as part of this work.

This report presents the key findings of the exploratory work. It reflects the collaborative efforts of all involved and offers insights into how some financial market participants are approaching the potential integration of DLT into their operations.

I would like to thank all those who contributed their time, expertise and openness to this work. Their engagement helped create a constructive dialogue on the opportunities and challenges of new technologies in wholesale finance.

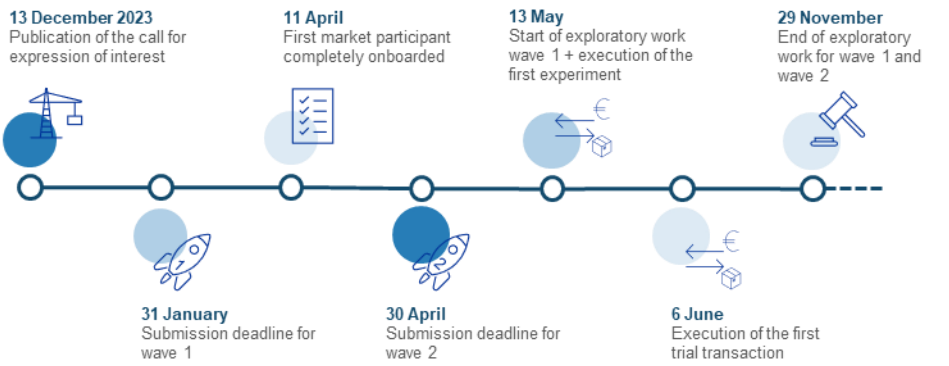
The Eurosystem will continue to monitor developments and help the market to innovate safely using new technologies. Our clear focus is on preserving the pivotal role of central bank money in the financial system and safeguarding the efficiency and stability of our TARGET Services and future financial market infrastructures.

1 Introduction

The Eurosystem's exploratory work on new technologies for wholesale central bank money (CeBM) settlement,[1] carried out in conjunction with financial market stakeholders, began in May 2024 and was successfully completed in November 2024 (Figure 1). The exploratory work consisted of (i) trials[2], with actual transactions recorded on distributed ledger technology (DLT) settled in central bank money in production environments, and (ii) experiments[3], with the settlement of transactions in test environments.

The high level of interest in this initiative, with a total of 64 eligible participants[4] across nine jurisdictions settling almost € 1.6bn in CeBM, confirmed the market interest in DLT and the use of tokens. Some of the financial stakeholders that took part have firm plans to develop and use DLT in wholesale financial markets.

Figure 1
Timeline for the exploratory work



Participants conducted numerous tests on a diverse set of use cases, covering both payments and securities business cases to assess and improve their understanding of the merits of DLT. The increased demand for enabling CeBM settlement of DLT-based asset transactions in Europe is evident from the high profile of digital bond issuances carried out in 2024, some of them under the umbrella of the exploratory work. It is also confirmed by discussions with market participants from commercial banks, central securities depositories, innovative newcomers, technology providers

1 See the page entitled "Exploratory work on new technologies for wholesale central bank money settlement" on the ECB's website.

2 **Trial**: In the context of the Eurosystem's exploratory work, exploratory activity consisting of real-life settlement in CeBM relying on TARGET Services (for the cash leg) and on the respective Eurosystem interoperability-based solution (for connectivity to market DLT platforms) made available to eligible market participants and eligible market DLT operators.

3 **Experiment**: In the context of the Eurosystem's exploratory work, exploratory activity consisting of mock settlement relying on the TARGET Services UTEST environment (used for test transactions) and on the respective Eurosystem's interoperability-based solutions (for connectivity to market DLT platforms) made available to eligible market participants and eligible market DLT operators.

4 A list of stakeholders participating in the exploratory work is available on the ECB's website.

and other relevant stakeholders. The exploratory work included a €300 million issuance by Siemens AG, the inaugural issuance of a digital bond by Slovenia as an EU sovereign, and the first digital bond issuance under Italy's "fintech" decree-law.

The use cases, along with the market feedback, highlight the potential benefits of tokenisation[5], which is expected to bring not only improvements at the technical level but also opportunities to reshape the current ecosystem. This could apply, for example, to the different functions of capital and payment markets and to the layers of intermediaries providing these functions across the full, end-to-end value chain, making markets more contestable.

The three solutions used were the Trigger Solution[6] provided by the Deutsche Bundesbank, the Full DLT Interoperability solution, DL3S,[7] provided by the Banque de France, and the TARGET Instant Payment Settlement (TIPS) Hash-Link solution,[8] provided by the Banca d'Italia.

The exploratory work provided the Eurosystem with a wide range of insights. In addition to the trials and experiments conducted by the market participants, internal Eurosystem-led experiments were conducted to allow the specific features of the three solutions to be compared. In their feedback to the Eurosystem, the New Technologies for Wholesale settlement Contact Group (NTW-CG)[9] and exploratory work participants stressed the importance of having a Eurosystem short-term offering to settle DLT-based transactions in CeBM available as early as possible following the conclusion of the exploratory work.

The Governing Council decided in February 2025 to expand its initiative to settle transactions recorded on DLT in CeBM.

Building on the learnings from the exploratory work, on 20 February 2025 the ECB announced the Governing Council's decision to expand its initiative to settle transactions recorded on DLT in CeBM.[10] The next phase will follow a two-track approach. First, the Eurosystem aims to develop and implement a safe and efficient platform for the settlement of DLT-based transactions in CeBM through an interoperability link with TARGET Services as soon as feasible (this is referred to as the Eurosystem short-term offering). Second, the Eurosystem will look into a more integrated, long-term solution for such settlements in CeBM. This will also include international operations, such as foreign exchange settlement, and engagement in international initiatives. While the precise approach chosen by the Eurosystem to be followed in the long-term is still to be defined, it will focus on improving the efficiency and competitiveness of current financial markets for securities and payments, without compromising on safety. This initiative is expected to support the progression towards a sustainable digital capital markets union (CMU) and savings and investments union (SIU) in Europe.

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5 **Token:** A representation of an asset on a distributed ledger.

6 Service description available on the ECB's website.

7 Service description available on the ECB's website.

8 Service description available on the ECB's website.

9 The NTW-CG was established in April 2024 to support the Eurosystem's exploratory work and to ensure an active dialogue with financial market stakeholders. The Terms of Reference of the NTW-CG are available on the ECB's website.

10 See press release of 20 February 2025.

2 Background

The Eurosystem already provides CeBM in digital/numerical form as it makes the euro available for wholesale settlement via its TARGET Services. It remains committed to providing CeBM and to supporting the settlement of wholesale transactions. The Eurosystem closely monitors market developments in the field of market infrastructures and payments regarding the use of innovative technologies, such as distributed ledger technology[11], for wholesale payments and securities settlement. It remains imperative that current and future euro wholesale payments and settlement infrastructures continue to operate safely and efficiently and to meet the relevant existing Eurosystem policies.

In 2022, the Eurosystem carried out research and analysis to determine market interest in the use of new technologies such as DLT.[12] This covered potential use cases and merits that could justify the use of new technologies for wholesale CeBM settlement compared with the ability of existing technologies to achieve the same results. The market stakeholders were enthusiastic about the potential benefits that moving to DLT could bring. These potential advantages of DLT compared with non-DLT environments include: (i) the possibility of having the three fundamental functions of an exchange (negotiation (trading), settlement and custody) on a single platform, thus reducing the high cost of intermediation; (ii) the ability to counter credit and settlement risks and lower liquidity requirements by programming conditional settlement; (iii) automation through smart contracts[13], including corporate actions; and (iv) lower barriers of entry for new players entering the ecosystem. However, achieving such advantages relies on assumptions such as the voluntary participation of the most important financial stakeholders from all financial segments. Market stakeholders confirmed that they were increasing their focus on DLT, with numerous initiatives being taken globally and in Europe. In addition, the entry into force of the DLT Pilot Regime Regulation[14] was expected to drive increased market demand for settlement in CeBM of the cash leg of such transactions. In the absence of a suitable CeBM settlement solution, market stakeholders expect that the private sector would

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11 **Distributed ledger technology** (DLT): A technology that enables the operation and use of distributed ledgers (as defined in Article 2(1) of the DLT Pilot Regime Regulation).

Distributed ledger: An information repository that keeps records of transactions and is shared across, and synchronised between, a set of DLT network nodes using a consensus mechanism (as defined in Article 2(2) of the DLT Pilot Regime Regulation).

12 Two dedicated market outreach activities were undertaken in 2022 to help inform the analysis: a questionnaire in May 2022 followed by an interactive multilateral stakeholder engagement meeting in September 2022.

13 **Smart contract:** Automatable, "contract-type" arrangement embedded in computer software. The software can validate, execute and record automatically on a DLT platform as soon as certain pre-programmed/predefined conditions have been met, based on information fed into the distributed ledger itself or received from a predefined (external) source.

14 Regulation (EU) 2022/858 of the European Parliament and of the Council of 30 May 2022 on a pilot regime for market infrastructures based on distributed ledger technology, and amending Regulations (EU) No 600/2014 and (EU) No 909/2014 and Directive 2014/65/EU (OJ L 151, 2.6.2022, p. 1).

provide alternative solutions, such as stablecoins.[15] However, they believe that such solutions would be suboptimal and carry higher risks.

Only practical experimentation with the CeBM settlement of DLT-based transactions in TARGET Services production environments can provide answers to the open questions.

The key takeaways from this Eurosystem market outreach exercise in 2022, while informative, were less than conclusive. The Eurosystem determined that, in the light of previous proofs of concept and related activities[16], only practical experimentation with the CeBM settlement of DLT-based transactions in TARGET Services production environments could provide answers to the open questions. Such experimentation could also help identify additional opportunities and "pain points" in the use of new technologies and DLT in wholesale markets. The Governing Council of the ECB therefore decided that continued analysis and exploration should be carried out in this area to answer the open questions in a controlled manner. This work would take the form of trials and experiments, with the trials involving CeBM settlement in the production environment and the experiments involving the settlement of transactions in the test environment.

The Eurosystem's exploratory work had two objectives. The first was to consolidate and further develop the ongoing work of Eurosystem central banks in this area. The second was to gain insights into how different solutions could enable interaction between TARGET Services and DLT platforms.

15 This assumption was confirmed by market stakeholders responding to a questionnaire shared in August 2024 in the context of the exploratory work. The stakeholders highlighted that in the absence of CeBM as settlement asset, the usage of stablecoins as a settlement asset for wholesale markets would emerge.

16 Such as Project Stella, Project Jura and experiments conducted by the Banque de France, experiments conducted by the Deutsche Bundesbank, and experiments conducted by the Banca d'Italia.

3 How the Eurosystem's exploratory work was set up

The Eurosystem's exploratory work, relying on the three Eurosystem developed interoperability-based solutions, was aimed at supporting innovation and maximising learning opportunities.

The Eurosystem offered the market three interoperability-type solutions for the exploratory work: (i) the Trigger Solution, consisting of a DLT infrastructure, which acts as technical bridge between the T2 and market DLT platforms[17]; (ii) the Full DLT Interoperability solution, DL3S, allowing the settlement of wholesale financial transactions in CeBM in a DLT-based account held on a Eurosystem-provided DLT platform; and (iii) TARGET Instant Payment Settlement (TIPS) Hash-Link, enabling settlement of wholesale financial transactions in CeBM in accounts on a platform set up for the Eurosystem that was similar to the existing TIPS.

Table 1

The Eurosystem provided three interoperability-type solutions for the exploratory work

Full DLT Interoperability	TIPS Hash-Link	Trigger Solution
The Full DLT Interoperability, DL3S, allowed the settlement of wholesale financial transactions in central bank money in a DLT-based account held on a DLT platform provided by the Eurosystem. In the context of the trials and experiments, cash tokens were issued as exploratory liquidity on DL3S with an escrow mechanism in place where central bank money was held in TARGET Services. The solution was developed and operated by the Banque de France on behalf of the Eurosystem. 40 entities from nine jurisdictions tested the Full DLT Interoperability solution.	The TARGET Instant Payment Settlement (TIPS) Hash-Link enabled settlement of wholesale financial transactions in central bank money in accounts on a TIPS-like platform set up for the Eurosystem. The solution tested interoperability between a market DLT platform and a central bank-operated payment system – a copy of TIPS – via an application programming interface gateway. In the context of the trials and experiments, cash balances were issued as exploratory liquidity on TIPS Hash-Link with an escrow mechanism in place where central bank money was held in TARGET Services. The solution was developed and operated by the Banca d'Italia on behalf of the Eurosystem. Five entities from four jurisdictions tested the TIPS Hash-Link solution.	The Trigger Solution consisted of a DLT infrastructure, which acted as technical bridge between T2 and market DLT platforms. Trigger Chain, based on Hyperledger Fabric, was the DLT infrastructure underlying the deployment of the Trigger Solution for the exploratory work. The solution was developed and operated by the Deutsche Bundesbank on behalf of the Eurosystem. 25 entities from five jurisdictions tested the Trigger Solution.

A bespoke operational and legal framework was put in place for the duration of the exploratory work (six months in total). This temporary set-up allowed for a deviation from the TARGET guideline[18] with respect to specific eligibility criteria for the exploratory work and procedures for the settlement of payments in T2 (e.g. reliance

[17] **Market DLT platform**: DLT platform provided by an eligible market DLT operator where assets are settled and delivered during exploratory work.

[18] Guideline (EU) 2022/912 of the European Central Bank of 24 February 2022 on a new-generation Trans-European Automated Real-time Gross Settlement Express Transfer system (TARGET) and repealing Guideline ECB/2012/27 (ECB/2022/8) (OJ L 163, 17.6.2022, p. 84).

on escrow accounts[19]). As the solutions were implemented outside the perimeter of TARGET Services to allow the exploratory work to be carried out quickly during a limited time horizon, the trials and experiments evidenced some limitations with each of the three Eurosystem solutions.[20] By design, the solutions tested could not benefit from the same level of service, security and robustness as the current TARGET Services including access via the Eurosystem Single Market Infrastructure Gateway (ESMIG)[21] and central liquidity management (CLM)[22]. Market DLT platforms and market participants were technically able to access the three Eurosystem solutions via the internet. Risks were mitigated by, for example, limiting the duration of the trials, applying robust criteria when selecting participants and monitoring activity, including in test systems.

Each solution provided its own connectivity and interfaces with the participants and, where relevant, with TARGET Services. This enabled the Eurosystem to explore different approaches, such as hashed timelock contracts (HTLC)[23] to ensure "atomic" settlement, or atomicity[24], which according to the Eurosystem's understanding refers to technically ensuring "all-or-none settlement" of delivery versus payment (DvP)[25] / payment versus payment (PvP)[26] transactions on a gross basis as close to simultaneously as possible.

Overall, the connectivity and onboarding process went smoothly.

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19 **Escrow account**: In the context of the exploratory work, an RTGS account held by the national central bank of the eligible participants. In the trials with both the TIPS Hash-Link solution, provided by the Banca d'Italia, and the Full DLT Interoperability solution, provided by the Banque de France, the escrow account was used to provide funding via liquidity transfers (i.e. transfers of CeBM from the participant's dedicated cash account) and to request the minting of exploratory liquidity. The funds on the escrow account belonged to the national central bank and were held on an intraday only basis.

20 Integration of the solutions within the perimeter of TARGET Services was not in the scope of the trials and experiments, which were conducted according to the principle of not changing the current legal, technical and operational framework of TARGET Services.

21 ESMIG is the single access point or gateway for all external inbound and outbound communication to all the TARGET Services.

22 Trials using the TIPS Hash-Link and Full DLT Interoperability solutions relied on the use of escrow accounts to lock/transfer liquidity from T2.

23 **Hashed timelock contract (HTLC)**: A conditional transfer agreement of certain assets where the condition is enforced by the underlying protocol. Time lock ensures that a transaction is time-bounded: the recipient only has a certain amount of time to accept the payment; otherwise, the asset is returned to the sender. Hash lock prevents counterparties to a transfer from claiming the assets without fulfilling the conditions stated in the transaction agreement. The combination of hash lock and time lock ensures secure asset transfer and can be used for delivery versus payment between different chains/protocols.

24 **Atomic settlement**: A form of settlement where (i) technical solutions are in place to automatically ensure that either both legs of the transaction are executed or neither leg is executed, and (ii) both legs are executed as close to simultaneously as possible. The concept of atomicity focuses on the technical dimension, rather than on the legal aspects.

25 **Delivery versus payment (DvP)**: A securities settlement mechanism which links a securities transfer and a funds transfer in such a way as to ensure that delivery occurs if – and only if – the corresponding payment occurs.

26 **Payment versus payment (PvP)**: A mechanism which ensures that the final transfer of a payment in one currency occurs if – and only if – the final transfer of a payment in another currency or currencies takes place.

4 Use cases

The Eurosystem adopted an open approach, with only limited restrictions imposed as to the type of use cases covered. A total of 58 distinct use cases[27] were completed during the exploratory work.[28] The use cases were explored in both experiments and trials. Experiments consisted of DLT-based mock transactions, with settlement of the cash leg in the test environments (including T2 test environments for experiments using the Trigger Solution). Trials consisted of DLT-based transactions with settlement of the cash leg in real CeBM in the T2 production environment.

More detailed information on the interoperability-based solutions developed by the Eurosystem is included in Annex I. A detailed overview of the use cases tested is available in the Annex II.

4.1 Market-led trials and experiments

Market demand for the Eurosystem's exploratory work was high.

Market demand for the Eurosystem's exploratory work was high, with use cases implemented using DLT across the current value chain of financial markets, extending beyond the CeBM settlement of the cash leg of transactions. They included functions such as trading, custody, settlement, clearing, commercial bank money payments and, separately, the full life cycle of DLT-based financial assets.

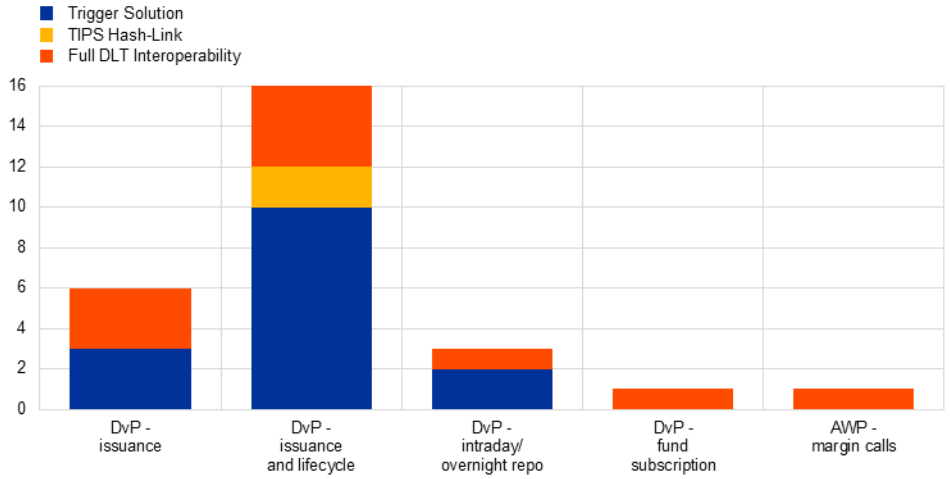
The trials focused primarily on securities-related use cases, and in particular on primary market operations (Chart 1). This focus can be explained both by the limited duration of the trials and by the early growth stage of the DLT financial ecosystem in Europe. In most cases, life cycle management (repo, margin calls, redemption) was also directly handled on DLT, including in many cases coupon payments being programmed and managed on DLT.

[27] **Use case**: For the purposes of this report, a use case is a business scenario implemented technically and operationally during exploratory work in mock settings (experiments) or real settings (trials) with one of the three solutions provided by the Eurosystem. The same scenario implemented across the three solutions counts as three distinct use cases.

[28] Including market-led trials and experiments, Eurosystem-internal experiments and Eurosystem experiments in collaboration with other central banks.

Chart 1

Trial use cases

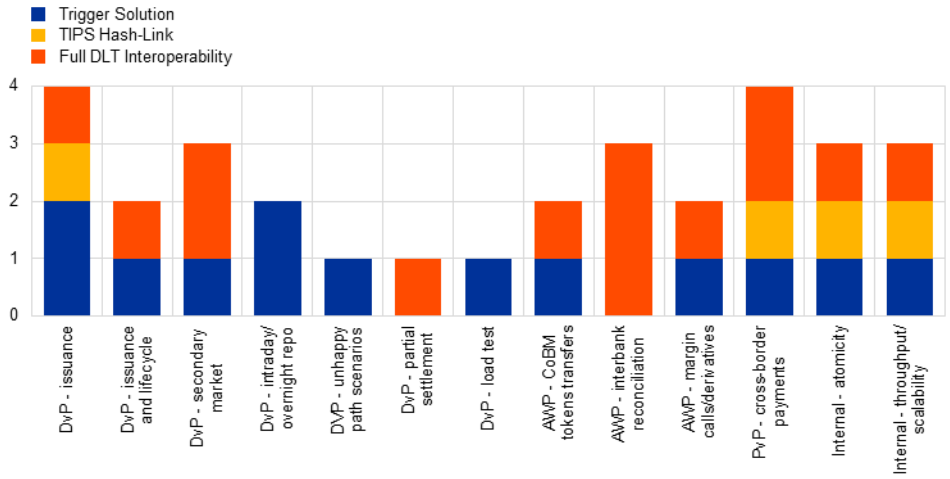


Notes: AWP stands for automated wholesale payments, DvP for Delivery versus Payment.

The experiments investigated a more diverse set of use cases, both securities-related and payments-related (Chart 2). Payments use cases included domestic payments (e.g. the issuance and transfer of commercial bank money tokens on DLT requiring interbank CeBM settlement) and international cross-currency payments.

Chart 2

Experiment use cases



Notes: AWP stands for automated wholesale payments, CoBM for Commercial Bank Money, DvP for Delivery versus Payment, PvP for Payment versus Payment, Internal for Eurosystem-internal.

Most participants tested only one of the three Eurosystem solutions. To enable a comparative analysis, market participants provided detailed reporting and direct

feedback on the experiments and trials by means of predefined key performance indicators (KPIs).[29]

4.2 Eurosystem-led experiments

Experiments were conducted internally by the Eurosystem (without market participants) to compare the three Eurosystem solutions. A first set of experiments investigated how each of the three solutions managed errors and failure scenarios and tested whether and how the result of the transaction remained consistent across the three Eurosystem solutions and the market DLT involved (e.g. ensuring atomicity, from an operational and technical perspective, so that the cash and the asset were returned to their original positions and so that one party did not have access to both cash and asset at any one time during a DvP process). Ensuring atomicity in all scenarios is achievable but by design more complex under an interoperable approach, where cash and assets reside on distinct technical environments, compared with a single-platform approach. Nonetheless, the experiments demonstrated that atomic settlement could be implemented under an interoperability model[30] leveraging programmability[31]. This requires that both the cash and asset sides agree to implement a common technical and operational approach (i.e. hash-link contracts or HTLC). One-side locking (where only the asset leg is locked) and the use of cancellation keys stored by the cash side as in hash-link contracts proved particularly reliable for ensuring atomicity in a broad range of scenarios.

A second set of experiments focused on how each of the three Eurosystem exploratory solutions could be scaled up. The experiments highlighted the scaling potential of the underlying infrastructures used by the three solutions, including centralised technologies and DLT, and identified the merits and bottlenecks associated with the set-ups used. Issues identified included constraints imposed by the set-up of the exploratory work and its operational parameters, and the fact that the solutions were provided outside the perimeter of TARGET Services (e.g. using a non-automated escrow mechanism). These constraints were not surprising, as the exploratory work was designed within specific operational parameters to protect the Eurosystem's TARGET Services environment as outlined in Chapter 3. Specific elements or features of certain solutions proved to have advantages over those of others. Any possible Eurosystem short-term offering will take into account the findings from the exploratory work, including these experiments.

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29 A total of 61 participants provided qualitative feedback in a KPI survey and 93 market stakeholders participated in the technical workshop to validate the high-level findings from the exploratory work. For details on the KPIs see "Proposed learning objectives for the Eurosystem exploratory work and Key Performance Indicators for the assessment of the findings" on the ECB's website.

30 **Interoperability**: The set of arrangements/procedures that allows participants in different systems to conduct and settle payments or securities transactions across systems while continuing to operate only in their own respective systems.

31 **Programmability:** The ability to automate processes by predefining actions to be taken if a specific event occurs.

4.3 The Eurosystem's participation in Project Meridian FX

Project Meridian FX explored how operators of wholesale payment infrastructures can enable interoperability with new technologies, such as DLT, with a focus on foreign exchange (FX) transactions. This was a joint project between the Eurosystem Centre and the London Centre of the BIS Innovation Hub (BIS IH), the Bank of England and the three Eurosystem solution providers on behalf of the Eurosystem. The project was built on the concept of a synchronisation operator[32] and then applied to a multi-currency foreign exchange transaction. In the experiments conducted during the project, the synchronisation operator successfully carried out PvP FX transactions atomically between different real-time gross settlement (RTGS) services in different jurisdictions, as well as between an RTGS service and a DLT ledger. All three Eurosystem interoperability solutions were successfully connected to the synchronisation operator and demonstrated their adaptability to perform cross-border settlement in standardised and harmonised test scenarios. The project offered additional learnings regarding the applicability of liquidity savings mechanisms and the possibility of linking complex multi-leg transactions across different infrastructures. More details can be found in the report on Project Meridian FX published by the BIS IH.[33]

[32] In 2023, Project Meridian explored the concept of synchronisation through the development of a synchronisation operator – a new entity that was designed to implement the simultaneous transfer of tokenised digital assets and funds in a mock UK housing transaction.

[33] See "Project Meridian FX: exploring synchronised settlement in FX" on the BIS's website.

5 Key findings from the Eurosystem's exploratory work

The availability of CeBM for settlement is viewed by the market as a major factor contributing to the growth of the DLT ecosystem in Europe.

The Eurosystem's exploratory work confirmed market demand for, and interest in, the settlement of DLT-based assets in CeBM, with an active ecosystem of incumbents and new entrants identified in Europe. Several market participants now wish to scale up and grow. The exploratory work highlighted the potential of the interoperability solutions tested to cater for a diverse set of use cases to support the growing market in a safe way while providing settlement in CeBM. Thanks to the diverse range of use cases and market stakeholders involved in the trials and experiments, the exploratory work provided valuable insights into the design of the three Eurosystem solutions, their respective merits and also the imperfections in their design and implementation.

Market participants indicated that DLT represents an opportunity to redesign processes and practices, including the distribution of roles, across the entire value chain.

Automation implemented in trials and experiments demonstrated that DLT could be applied to a broad range of operations and processes across the entire value chain, extending beyond settlement. In terms of business logic, most use cases were implemented with automation or programmability on the asset side (i.e. they were deployed on market DLT platforms or in commercial banks' own DLT environments).[34] Noting the benefits offered by programmability, intermediaries have started to actively investigate changing the current scope of their services with the adoption of DLT. The exploratory work showed how each of the functions in the current value chain could be implemented on DLT, combining programmability features and the availability of information on-chain to increase efficiency. As the Eurosystem adopted a very open approach to the exploratory work, with no restrictions imposed as to the type of use cases covered, in some cases market participants played different roles in the business scenarios tested. This indicates that the adoption of DLT could affect the current ecosystem, market structures and possibly the distribution of roles in capital and payments markets. Such changes could occur to the extent needed to enable a safe, efficient, innovative and competitive SIU and to the extent allowed by (future) regulation.

A move to DLT has the potential to address and overcome shortcomings in today's ecosystem.

Overall, it appears that a move to DLT and tokenisation, enabling a new innovative approach, has the potential to help address and overcome the shortcomings in today's ecosystem – namely fragmentation, complexity and technological inefficiencies – that are impeding the growth of a digital and sustainable SIU in Europe. Overcoming the remaining legal and regulatory barriers is critical to this objective. In addition, while the availability of CeBM is identified as a prerequisite for DLT to be scaled up and developed in a safe and stable way, barriers to scalability and other barriers would also need to be addressed.

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[34] Programmability of the whole, end-to-end transaction chain was not possible for all transactions, but was instead simulated. This was due to the interfaced nature of the interaction with the CeBM cash leg (i.e. use of escrow accounts). This construct was specific to the operational framework designed for the exploratory work. Two use cases tested programmability deployed directly in the Eurosystem solutions: one in the Trigger Solution (smart contract of derivatives); another in the Full DLT Interoperability (smart contract to enable partial settlement).

The exploratory work identified how interoperability could be established between market DLT platforms and TARGET Services via the three solutions offered by the Eurosystem for the purpose of safe and atomic settlement. Interoperability was achieved across a diverse type of market platforms, including private permissioned DLT platforms, public permissionless DLT platforms, and shared platforms. However, each market DLT platform operated on its own choice of technology and under its own practices, with a lack of industry-wide market practices and standards. In addition, the exploratory work highlighted the diversity of legal regimes in Europe for DLT securities, including at national level.

The fragmentation of DLT applications and a lack of interoperability in a broader sense are hindering the development of liquid DLT-based markets, with investors and issuers facing high costs for connecting to multiple platforms. This also limits the possible benefits of DLT. The exploratory work highlighted the need for CeBM settlement of DLT-based transactions to actively contribute to a more integrated and efficient DLT ecosystem. Fragmentation needs to be contained, while being mindful that innovation must not be stifled. The Eurosystem has consistently contributed to standardisation and harmonisation and hence to the integration of financial market infrastructures and markets in Europe, most notably by providing its TARGET Services and by acting as a catalyst.

6 User expectations for a Eurosystem short-term offering

Market participants expressed a clear demand for enabling CeBM settlement for DLT-based transactions.

The exploratory work confirmed the demand for enabling CeBM settlement for DLT-based transactions and the importance of keeping up the momentum to help maintain the European financial industry's innovation lead. The market appreciated the Eurosystem's exploratory work, noting, at least for the limited volume, that the performance of the Eurosystem interoperability solutions explored was good enough to provide a potential basis for a Eurosystem short-term offering.

Continuous market feedback suggests that the Eurosystem providing a short-term CeBM offering is seen as a key factor in enabling DLT to be adopted and scaled up. It would also help manage the risks that the use of other settlement assets, such as stablecoins, could create for safety and efficiency, and for financial stability more broadly. Market feedback indicates a willingness on the part of European market stakeholders to accept the strict conditions that would be attached to a Eurosystem short-term offering. Market participants have not expressed a unanimous view on the long-term approach that the Eurosystem should take. Some argue in favour of an interoperability-based ecosystem despite its limits, inefficiencies and barriers. Others highlight the advantages of a more innovative, competitive and integrated ecosystem.

Market participants expressed a preference for having a single Eurosystem offering within a short time frame.

While recognising the importance of a short time to market, market participants would prefer to connect to one Eurosystem short-term solution.

Market participants expressed a preference for minimising the liquidity impact of keeping the assets (and, where applicable, cash) locked in for lengthy periods at the expense of increasing the risk of settlement fails and the subsequent need for retries. Market participants also indicated a preference for flexibility in the definition of the timeout of the transaction, which should be short by default (a matter of minutes at the most). While participants in Eurosystem trials and experiments were satisfied overall with the atomicity and reliability of the Eurosystem solutions, they also fully acknowledged the limited scale, diverging allocation of responsibilities across solutions and trail-blazing nature of the trials and experiments. Several participants flagged the inherent limitations of an interoperability model regarding the extent to which distinct ledgers for money and assets could be synchronised in (close to) real time. Some market participants flagged the limits of HTLC, and specifically the risks and complexities of managing related timeout errors. Some scenarios require contingencies to be initiated when using HTLC, and this had to be done manually in the context of the trials and experiments, which was seen as a key area for improvement. Several market participants highlighted their interest in investigating the concept of cancellation keys to allow the asset and cash to be returned without the need to wait for the transaction timeout (for example in the

event of errors).[35] In addition, participants who experienced the escrow mechanism in trials highlighted the need for liquidity to be manageable overnight, rather than limited to intraday only ("intraday only" use being a design feature specific to the trials).[36]

The exploratory work demonstrated the technical and operational feasibility of ensuring atomic settlement under an interoperability model. However, the complexity and level of expertise required to do so was also highlighted.[37] The level of technical experience and knowledge on ensuring atomicity from a technical and operational perspective differs across market stakeholders. Furthermore, the way in which the perimeter of "atomic settlement" is defined and understood also varies substantially. While acknowledging this, in formulating their expectations for a Eurosystem short-term offering, most market participants nevertheless focused on the need for gross settlement that is as close to simultaneous as possible in an interoperability context and is carried out on an "all-or-none" basis.

While some market DLT operators have already developed procedures to ensure atomic settlement from a technical and operational perspective, most market participants assumed that atomic settlement would work smoothly and that the Eurosystem would play a key role. In the Eurosystem's exploratory work, different approaches were adopted by the central banks providing the solutions (the Deutsche Bundesbank, the Banque de France and the Banca d'Italia) in ensuring atomic settlement technically and operationally. Specifically, the solutions differed in terms of the interoperability mechanism provided, the programmability enabled and the rulebook for connecting. While this situation was acceptable for the Eurosystem's exploratory work, a more robust and clearly defined delineation of responsibilities would be required for a Eurosystem short-term offering.

Market participants identified several improvements to enhance automation that could be considered in the context of a Eurosystem short-term offering.

To ensure technical neutrality and provide greater scope for innovation, a short-term offering should be use case-agnostic and capable of supporting both securities and payments use cases, as well as linked or conditional transactions[38]. It should also ideally be agnostic to other currencies available on T2. Market participants identified several potential improvements to automation that could be considered in the context of a short-term offering. These included (i) the use of application-to-application (A2A) processes; (ii) the elimination of manual interventions to ensure atomicity; (iii) the ability to monitor and retrieve information and transaction statuses from the Eurosystem short-term offering in real time and on an automated basis; and (iv) end-to-end transaction identifiers.

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35 Market stakeholders also referred to the specific implementation of the TIPS Hash-Link solution, where cancellation keys are provided by the Eurosystem via an API gateway to the parties to the transaction. Under certain conditions, these enable the buyer/seller to unlock securities locked on the market DLT during the DvP process.

36 For example, this design feature avoided the need for complex temporary rules governing minimum reserve holdings.

37 Different approaches were taken across the Eurosystem's solutions, with either greater responsibility and discretion left to the market on how DvP is implemented (Trigger Solution) or the stronger involvement of the Eurosystem via its technical solution, its interoperability mechanism and the attached onboarding and connectivity requirements (TIPS Hash-Link and Full DLT Interoperability).

38 "Conditional transactions" refers to XvP, where the payment is executed atomically in conjunction with the settlement of one or more assets "X" on the market DLT side (two-leg or multi-leg transactions).

7 Next steps for the Eurosystem

An interoperability model would be acceptable as a transitory step towards creating the optimal long-term-state for leveraging DLT, according to market participants.

Many market participants that directly or indirectly engaged in the Eurosystem's exploratory work consider an interoperability model for a Eurosystem short-term offering to be a good compromise in the short term as the market evolves, while noting that this should not be misconstrued as an indicator of how the long-term solution may be approached. Market stakeholders would find an interoperability model acceptable as a transitory step towards a safe, efficient, innovative and competitive long-term-state for leveraging DLT. Market stakeholders therefore indicated a willingness to accept some limitations in the context of an interoperability model where CeBM and assets do not reside on the same technical platform, provided that such limitations are mitigated with well-designed procedures, interoperability mechanisms and information flows to ensure atomic settlement (i.e. simultaneous gross, all-or-none settlement) of DvP/PvP transactions as much as possible.

By providing a short-term offering for CeBM settlement of DLT-based transactions, the Eurosystem will continue to support market needs and market innovations while at the same time making progress with its investigations into the long-term outlook for the ecosystem.

The Eurosystem, taking note of the findings from the exploratory work, is committed to proceeding with the short-term offering and longer-term work as announced by the ECB on 20 February 2025.[39] Feedback suggests that market stakeholders see advantages in the Eurosystem's two-track approach, as the DLT-based market is maturing, and innovation should be fostered. Market participants consider it important for markets to be contestable (so that services provided to them improve through competition or so that they can take on new roles themselves). By providing a short-term offering for CeBM settlement of DLT-based transactions, the Eurosystem will continue to support market needs and market innovations while at the same time progressing investigations into the long-term outlook for the ecosystem. The details of the approach chosen by the Eurosystem to be followed in the long-term is still to be defined. Participation in future Eurosystem market contact groups and any experimentation on a long-term approach are not dependent on participation in the Eurosystem short-term offering. Details of governance structures including market contact groups will be published in due course.

The Eurosystem will continue to act as coordinator and catalyst for harmonisation and standardisation as the scope of DLT goes beyond current financial market infrastructures and touches on all parts of the value chain. Harmonisation and standardisation require coordination across market players and market segments and, ultimately, the adoption of harmonised market practices and standards. The exploratory work highlighted that the legal regime governing the use of DLT in Europe for wholesale financial markets is still at a relatively early stage. Within the controlled environment of the Eurosystem's exploratory work, novel practices (e.g. interlinking central bank money and commercial bank money transfers at a technical level) were tested in comparison with the current ecosystem. This is indicative of a possible restructuring of current markets and intermediation with the adoption of DLT. The DLT ecosystem would benefit from less divergence of technologies, market practices and operating models, and from the application of technical

[39] See press release of 20 February 2025.

standards, which could improve scaling. In addition, adjusting legal, fiscal, and collateral frameworks at a pan-European level for DLT will be important in order to scale up and to reap the expected benefits. As part of the long-term work, the Eurosystem will engage with other central banks to consider how a long-term European ecosystem could be seamlessly connected (globally) in line with the objectives of the G20 on cross-border payments. In particular, the Eurosystem, together with non-euro area central banks making their currency available in T2, will work closely on multi-currency functionalities. In addition, the Eurosystem will undertake detailed analysis of all these aspects in conjunction with the relevant public sector bodies, while also liaising with market stakeholders at both the European and international levels.

Annexes

Annex I – Interoperability-based solutions tested

More

Annex II – Comprehensive overview of trials and experiments

More

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PDF ISBN 978-92-899-7306-9, doi:10.2866/1304803, QB-01-25-147-EN-N
HTML ISBN 978-92-899-7305-2, doi:10.2866/8248151, QB-01-25-147-EN-Q